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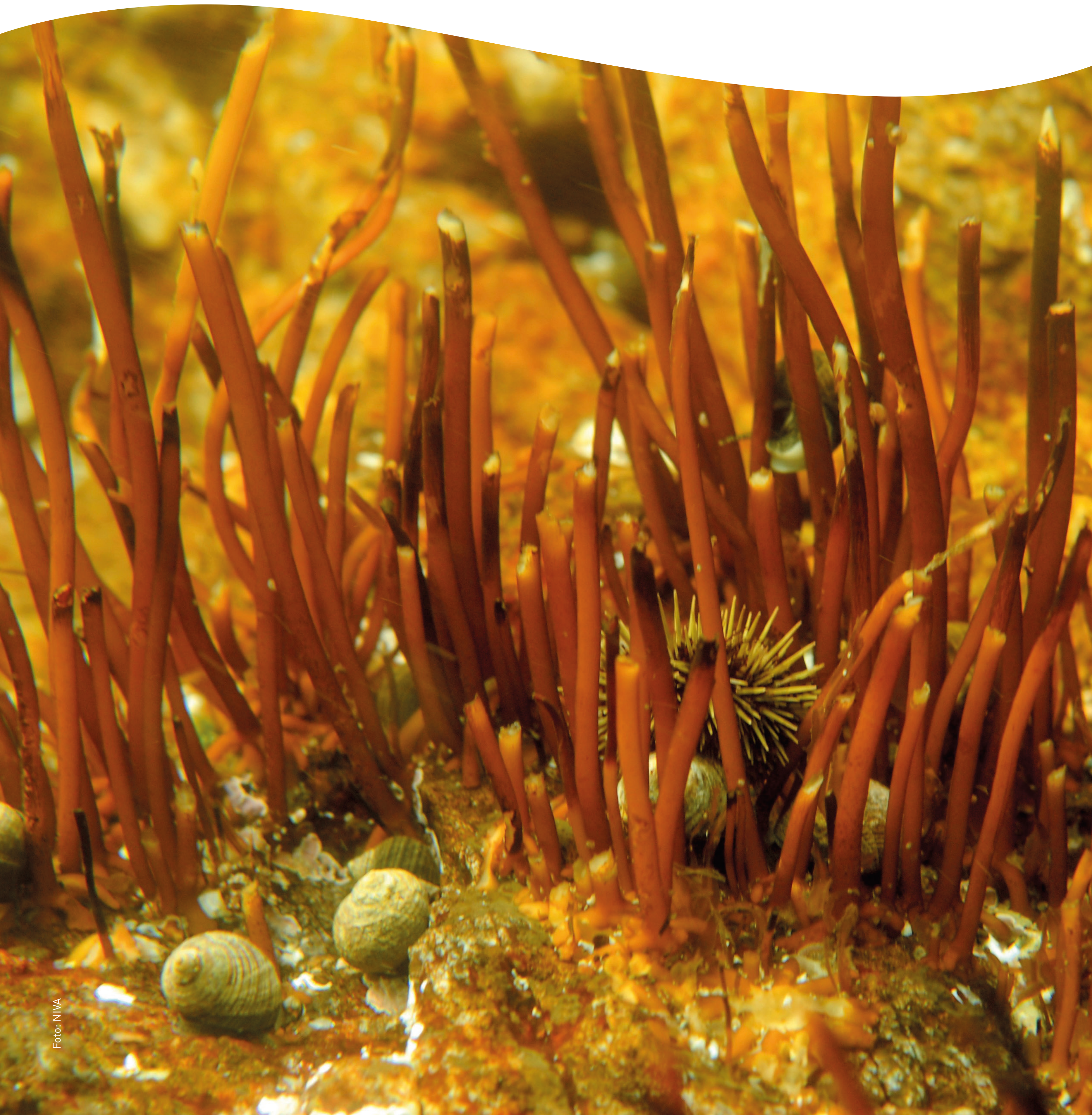
Regrowth of kelp after removal of sea urchins

(Strongylocentrotus droebachiensis)



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REPORT

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Summary

With few natural predators, green sea urchins (*Strongylocentrotus droebachiensis*) have grown in numbers, grazed down large kelp forest areas in Northern Norway into urchin barrens. NIVA deployed three underwater cages outside Tromsø, Northern Norway during Autumn 2018, removed all urchins within these cages and followed the cages closely until Summer 2019. The first kelp individual was observed in the middle of March, and by the end of May, the seafloor in the cages were covered with 80-100% of algae, especially brown algae *Desmarestia sp.* and *Alaria esculenta*. Sugar kelp (*Saccharina latissima*) was also present. The study showed that kelp species could re-establish in cages where sea urchins were kept at low abundance. However, once kelp had re-established, the area inside the cages increased in interest for the sea urchins, who climbed into the cages and grazed on the algae. This small scale pilot-project would need an up-scaling of cage sizes and cleaning efforts to improve the survival rate of the kelp. At present, the density of urchins in Troms are probably sufficiently high to allow a sustainable sea urchin harvesting. However, research is needed to assess the required harvested amount of sea urchins to promote kelp forest recovery, and at the same time allow the sea urchin industry to have access to their resources.

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Regrowth of kelp after removal of sea urchins (*Strongylocentrotus droebachiensis*)

Preface

This report presents the outcome of the project «Kråkebolleburer og settling av tare i Tromsø" that has been conducted by NIVA for Brace Inc. and Urchinomics. The project has been led by Pernilla Carlsson in close collaboration with Hartvig Christie. Our main contacts at Brace Inc. has been Susanna Yip and Brian Tsuyoshi Takeda at Urchinomics. Inspection of cages and sampling has been conducted mainly by Pernilla Carlsson, Hartvig Christie and Magnus Aune (Akvaplan-niva). David Hammenstig and Rosalyn Fredriksen (Akvaplan-niva) and Peter Leopold have also contributed to the field work. David Gonzáles (Buendia photography) has been filming and documenting the experiments throughout the project for Fuglefjellet AS. Additional photo material from NIVA have been delivered to Urchinomics and Brace Inc. during the project. We thank everyone involved for a very good cooperation.

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Summary

With few natural predators, green sea urchins (*Strongylocentrotus droebachiensis)* have grown in numbers, grazed down large kelp forest areas in Northern Norway into urchin barrens. To combat this, the company Urchinomics initiated a business idea where urchins from urchin-barrens could be harvested and sent to aquaculture for feeding to a proper size before being sent to the international market. However, they also wanted to find out whether this work would have a positive impact on kelp forests.

NIVA deployed three underwater cages (9m^2 each) outside Tromsø, Northern Norway during Autumn 2018, removed all urchins within these cages (300-600/cage) and followed the cages closely until Summer 2019, removing urchins that had climbed into the cages. The first kelp individual began to grow in the middle of March, and by the end of May, the seafloor in the cages were covered with 80-100% of algae. The kelp species *Alaria esculenta* were growing on the nets as well. Algae composition was dominated by the brown algae *Desmarestia sp.* and *Alaria esculenta.* Some sugar kelp individuals *(Saccharina latissima*) were also present. We also observed the presence of other species in the cages during the surveys, such as crabs, snails and sea stars.

The study showed that kelp species such as *Alaria esculenta* and *Saccharina latissima* could re-establish in net cages where the sea urchins were kept at low abundance. However, once the kelp had re-established, the area inside the cages seemed to increase in interest for the sea urchins, who climbed into the cages and grazed on the kelp. This project was a pilot project in small scale, and an up-scaling of cage sizes and cleaning efforts might improve the survival rate of the kelp. An economic incitement for removal of sea urchins have the potential to be beneficial for re-establishment of the kelp forest in urchin barren areas. At present, the density of urchins in Troms are probably sufficiently high to allow a sustainable sea urchin harvesting. However, research is needed to assess the needed harvested amount of sea urchins to promote kelp forest recovery, and at the same time allow the sea urchin industry to have access to their resources. A next research step would be to investigate the spatial scale, time and efforts needed for removing urchins to allow kelp forest to re-establish in urchin barrens.

1 Introduction

1.1 Kelp forests and sea urchin interactions

Kelp forests are a very important marine coastal ecosystem. The kelp species *Saccharina latissima* and *Laminaria hyperborea* form dense forests in the sublittoral zone along the Norwegian coast. Kelp forests are among the most productive systems in the world and provide home for numerous species, offering food, nutrients, habitats and shelter.

The total kelp forest area along the Norwegian coast line was estimated to be about 7900 km^2 in 2011, but the estimated loss (at that time), mainly due to sea urchin grazing, was about 9800 km^2 meaning that the total area covered by kelp was less than 50% of the original coverage (Gundersen et al., 2011). Since kelp store and export carbon dioxide (CO_2) to deep ocean basins, the extension of Norwegian kelp forests is of importance in a climate change perspective as well. Numbers estimated by Gundersen et al. (2011) showed that the biomass of kelp forests in Norway store about 29 million tonnes of CO_2. If the grazed area of kelp forests (~9800 km^2) re-establish, the recovered kelp forest would store about 36 million tonnes of CO_2. Transport of kelp debris and fragments to deeper water of the estimated 2011-standing stock of kelp, contributes to sequestering 2.3 million tonnes CO_2/year, using a moderate assumption (Gundersen et al., 2011). Including total recovery of the grazed area, this number would increase to 2.9 million tonnes CO_2/year (Gundersen et al., 2011). In addition, kelp debris is important provider to nearby deep sea ecosystems with organic matter and nutrients and connect e.g. the littoral zone with the deep sea (Ramirez-Llodra et al., 2016).

Causes of the loss of the kelp forests include climate change, increased runoff of particles, increased nutrients and growth of filamentous algae (Gundersen et al., 2014), particularly in south and west Norway. But the most important cause is very high densities of sea urchins, which have grazed the kelp forest (Christie et al., 2019, and references therein). The dominating sea urchin species in the North-Norwegian barrens are the green sea urchin (*Strongylocentrotus droebachiensis*). However, at the same time, this species is a resource that may be harvested for its high value gonads to international sushi and gourmet restaurants.

Kelp forests have re-established in mid-Norway due to reduced and even lack of urchins in these areas. The reduction in sea urchin populations is due to several factors, such as higher water temperatures that may reduce sea urchin larval development (Fagerli et al., 2013) and predation by crabs (Fagerli et al., 2014, Christie et al. 2019). The dynamics between predators of crabs, crabs and urchins are important factors that may explain both blooms and declines of sea urchin populations. Brown crab (*Cancer pagurus*) is common in mid-Norway and its northern distribution border is around Tromsø at 70°N. The brown crab abundance is low in Troms, implying low sea urchin predation. King crabs are spreading from eastern Finnmark, and individuals were caught by commercial fishing boats in Tromsø (Balsfjorden) last winter (pers. observations 2019). However, at present they occur at lower densities than in Eastern Finnmark, where recovery of kelp has been suggested to be facilitated by king crabs (Christie et al., 2019). At present there are still large coastlines where sea urchins dominate. A recent overview of the distribution of sea urchins and kelp forests are shown in **Figure 1**.

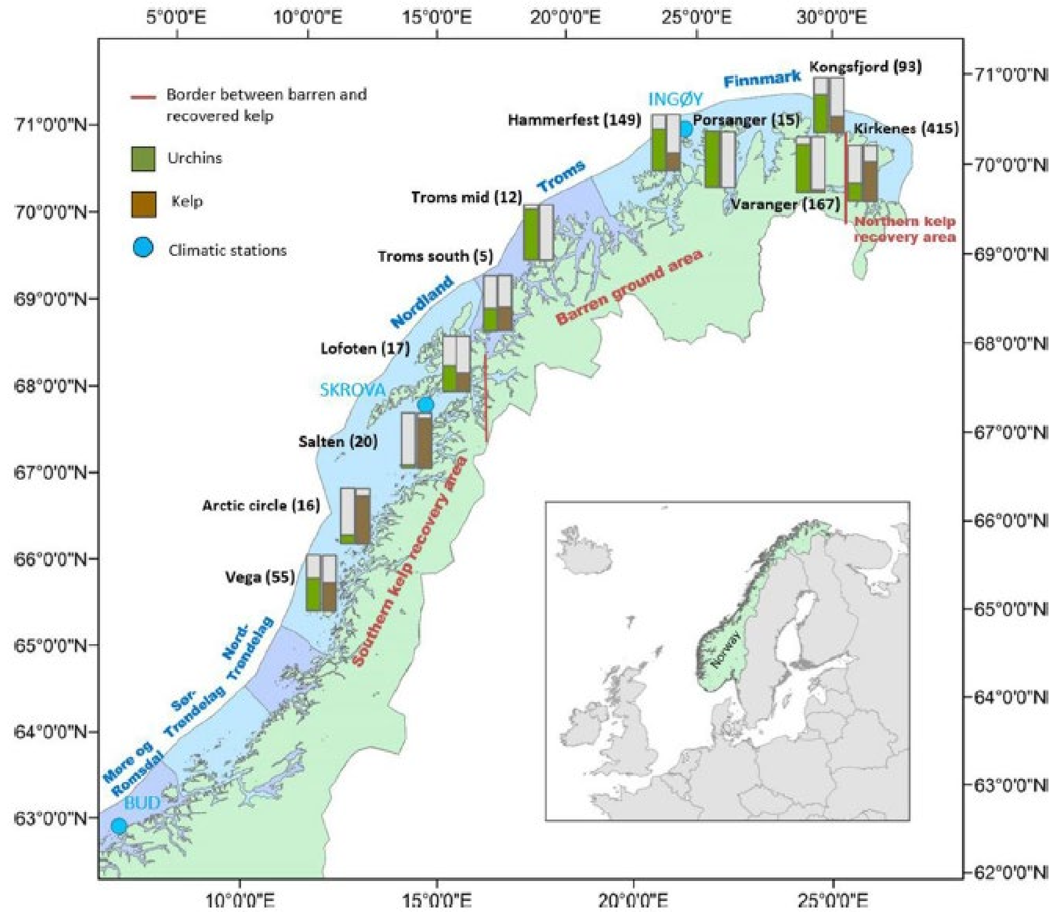

Figure 1. Distribution of sea urchins (*Strongylocentrotus droebachiensis*) and kelp (*Laminaria hyperborea* and *Saccharina latissima*). The urchin barren area is between the brown lines, i.e. roughly between Lofoten and Varanger. Figure from Christie et al. (2019).

1.2 Aim of study

Due to all the benefits (ecosystem services) of kelp forests it would be of great value to recover lost kelp forests. For commercial harvesting of sea urchins, sustainable resources of sea urchins over time is important. A regulated harvest of urchins that allow a gradual kelp recovery could be a win-win situation. The aim of this study was to investigate whether kelp may recover if the abundance of urchins is reduced in a small-scale pilot study. If successful, this can be used as an environmental argument for harvesting and selling urchins to the market. It was outside the scope of this study to investigate any combined effects of other parameters that also may affect kelp forests.
As a pilot, this study was limited to test if hand picking of urchins could initiate kelp recovery in small experimental plots.

2 Methods

The experiment was done by caging three restricted shallow areas dominated by sea urchins and with no visible kelps/seaweeds. Three net cages were deployed 29th of October 2018 at 2m depth (low tide) in the sound between Kvaløya and Tromsø (**Figure 2**), northern Norway (69°41'34N 18°53'35E). The cages (~9m^2 each) were cleaned for urchins by handpicking by divers.

2.1 Caging

The cages were made by NOFI, a local fishing equipment company. The bottom line was 12 m of 13mm, flexible chain that was tightened to the seafloor. A 1 m high net (with ca 10 mm mesh size) were mounted to the chain and kept upright in the water by floats. The cages were open on the top to allow sunlight for seaweed growth. Each cage should theoretically make an area of 9m^2, but the form of each cage had to be adjusted to the bottom topography. The inner cage (Cage 1) was on an almost flat bedrock, while Cage 2 and Cage 3 (the outer one) were both on a sloping bedrock towards boulders/cobble stones. The outermost Cage 3 was located on a site with high current speed. Sand dominated the deeper seafloor below the cages.

2.2 Sea urchin removal and algae coverage

The total number of sea urchins removed from the different cages were counted/estimated to be:
Cage 1: 200
Cage 2: 500
Cage 3: 600

A large fraction of the sampled urchins (ca 25%) were put in transport boxes and sent for further feeding to enhance gonad size. 100 sea urchins collected from the area (29.10.2018), were used to determine the size frequency (diameter) distribution of population. The divers counted sea urchin density at the location in 10 à 50x50 cm frames when the cages were deployed.

After the deployment of the cages, we have cleaned and checked the cages for intruding urchins regularly. At first on a monthly basis, but because the urchins were able to climb into the cages even though there is a strong current in the sound, we increased our efforts to keep the cages clean from urchins and began removing urchins every 2nd -3rd week. At each visit to the cages, species present in the cages were registered as well as algae coverage. Due to time, weather and current limitations, we did not count the individuals. The algae coverage was estimated as percentage of seafloor area in each cage covered with algae. The number of *S. laminaria* individuals were counted if present. However, due to tidal currents, the counting was rounded off to nearest 10th. The period November-February, when the sun does not rise above horizon or when the sun is low, was a challenging time for doing this job, since we needed daylight and low tide for practical as well as safety reasons.
The work has been documented by own photos and videos in addition to a professional underwater photographer from the company Fuglefjellet who followed our work and documented the growth of the algae from October 2018 until June 2019.

2.3 Fauna observations and sampling

Samples of kelps (4 replicates) were taken 26 June 2019 and analyzed for presence of small animals. The samples were taken by divers and sealed in a bag, washed and sieved (250 µm) for collecting the animals that had colonized the kelp in the cages.

Traps made of ropes were deployed in each cage (3 replicates/cage, n=9) and in between the cages (3 replicates/location, n=9) in late June 2019. This is a method developed by NIVA (see Christie et al. (2009) for further information) and was applied to compare the fauna composition inside the cages with the fauna composition on the urchin barren. The traps were deployed for two days and then sampled by divers and three traps from each site were pooled. The fauna samples from the algae and the fauna traps were preserved and species present were counted and identified.

Figure 2. Position of deployment of cages in Sandnessundet. Map from The Norwegian Coastal Administration, picture by Pernilla Carlsson.

3 Results and discussion

3.1 Sea urchin density and their size distribution

The size of the urchins collected in October 2018 ranged between 20 and 74 mm, averaging 41 mm and the density of the individual frame counts ranged from 24 to 248 urchins per m^2, with an average of 114 urchins/m^2. Visual inspections of the area between the cages at similar depths did not reveal any kelp species or other algae, during the experimental period. This shows an area with a high density of large sized sea urchins, and no algae vegetation. The only animals observed within the cages in October 2018 were a few sea anemones, hermit crabs, snails and barnacles.

3.2 Re-colonisation of kelp

The re-colonisation of kelp and other algae within the sea urchin cleared cages are illustrated in **Figure 3** and **Figure 4**. Urchins were removed from the cages 1-2 times/month during November 2018 and September 2019, and the first kelp plants was observed in March in cage 1. In April, the cages had an algae coverage of about 15-30 % and between 10-30 kelp individuals/cage and from May and onwards throughout the summer, the algae coverage was 60-100% algae. In general, the amount of *S. latissima* varied between 5-10 individuals/cage on the seafloor during May-August. At that time, we actually had to remove *A. esculenta* from the floatation rings and the cage net to prevent the cage from sinking (**Table 1**). The *A. esculenta* individuals were not counted (due to tidal currents and working conditions), but the visual estimate was a very high cover on the nets, as shown by Fuglefjellet videos. However, in August and September, the urchins had invaded the cages and grazed heavily inside the cages as well as on the nets themselves, which had sunk down a bit due to the total weight of the algae, the urchins and growth of *Balanus spp.* on the floatation rings. As a result, the algae coverage decreased to around 30% in August and further to 5% and 10% (cage #1 and #2, respectively) in September due to grazing. Nevertheless, some kelp was still growing on the flotation rings on these cages. The algae in cage #3 were more rapidly grazed, and only a few kelp individuals were observed in September. It is worth mentioning that the floatation rings also hosted algae, as well as urchins during the experiment. When the cages were removed in late October 2019, there were a few (<10 individuals) *S. latissima* on some of the rings, a high abundance of *Balanus spp.,* but no urchins. These kelp individuals might have survived grazing due to movement of the rings, which prevents the sea urchins to stick to the buoy.

Figure 3. Development in the cages from deployment (upper left) in October 2018, to early growth in April 2019 (upper right), followed by full cover of the cages and nets in May 2019 (lower pictures).

Figure 4. An example on the grazing efficiency (upper left and right) and abundance of urchins; from cages covered by different algae in late June (low left; *Saccharina latissima* and low right; *Alaria esculenta* and *Chorda filum*) to grazed cages in early August (mid and upper right). The upper right picture also shows how the cages eventually became too heavy from settled algae and fauna and began to sink.

Table 1. Urchins removed during the experiment and growth of kelp in the cages.

	Removed urchins (range)	Average area of cage covered by algae (%)	Average counted individuals of Saccharina	Observed length range (cm) Saccharina
15.nov	0-10			
13.dec	5-30			
15.jan	10-50			
29.jan	10-40			
11.feb	3-40			
12.mar	2-100		0.3	<10
12.apr	10-150	23	>30	<25
10.may	5-50	77	Not counted	<25
27.may	5-40	90	<5	10-50
26.jun	50-100	90	>30	10-50
02.aug	50-100	27	>5	10-50
19.sep	100-250	5		

3.3 Observed fauna

During every visit to the cages, a short investigation and recording of species observed was done for each cage. Since the observation was made at the same time as sea urchins were removed, we might have disturbed and scared away e.g. fishes. Species observed in the cages are shown in **Table 2**.

Table 2. Species found in the cages.

Cage 1	Cage 2	Cage 3
Species observed first time in October		
Balanus sp.	*Balanus sp., Urticina sp.*	*Balanus sp.,*
Species observed first time in November-March		
Sculpin, hermit crabs (*Pagurus bernhardus*), *Hyas araneus*, Dog whelk (*Buccinum undatum)*, sea stars (*Asterias rubens)*, red sea squirt	Sculpin, hermit crabs (*Pagurus bernhardus*), *Hyas araneus*, Dog whelk (*Buccinum undatum)*, sea stars (*Asterias rubens, Solaster sp.), Carcinus maenas*	Sculpin, hermit crabs (*Pagurus bernhardus*), *Hyas araneus*, Dog whelk (*Buccinum undatum),* Gunnel *(Pholus gunnerus),* nudibranch eggs
Species observed first time in April-August		
Solaster sp., various small fish (<5cm)	Polychaetes on *Saccharina latissima*	

3.4 Kelp and mobile fauna

Since most kelp forest areas in Troms are heavily grazed by sea urchins there are few source habitats for kelp fauna in the nearby area. Hence, the recovery of a rich kelp fauna would be expected to take longer time than if the cages were closer to intact kelp beds. The short duration of the kelp in the cages before the sampling in June also hampers the degree of kelp fauna recolonisation. However, typical kelp fauna species such as amphipods (family *Ischyroceridae*), small snails (*Gibbula spp., Margarites spp., Lacuna spp.)*, and polychaetes was able to colonize the cages despite these obstacles. More species and a more abundant fauna were found in the traps inside the cages with kelp, compared to the traps in the urchin barrens (**Table 3**). A trend of higher colonization to the outer sites (cage 2 and 3) with more water currents was found for the traps, with twice as many individuals in cage 2 and 3 compared to cage 1 and the control. The algae samples (handpicked in bags) consisted mainly of a mix of medium sized (20-60 cm) *Alaria* and *Saccharina* kelps (about 10 plants of each species per sample) and a small fraction of smaller brown, red and green algae. As it was difficult to sample single kelps in this dense vegetation, the samples varied in number of kelps and in composition of kelp species, that could cause differences in the kelp fauna composition. Hence, the samples only reflect the level of fauna species number and number of individuals on the kelp individuals at the time of sampling.

Table 3. Amount of animal species and individuals found in animal traps and on algae samples in late June 2019.

Sample type	Trap	Trap	Trap	Trap	Trap	Trap	Algae	Algae	Algae	Algae
Site	Control 1	Control 2	Control 3	Cage 1	Cage 2	Cage 3	Cage 1 a	Cage 1 b	Cage 2	Cage 3
No of species	4	6	8	4	19	12	13	10	8	18
No of individuals	4	20	31	31	52	69	47	33	21	59

Although urchin barrens are reckoned as a stable state even when the density of the urchins are low, this study (as also found earlier, see Norderhaug and Christie 2009) documents that kelps can settle and grow after removing sufficient numbers of urchins. Recovery of fauna to newly recovered kelp beds are however poorly studied. In this study he number and density of kelp forest species was (as expected) low among the established kelp plants, and far below what is found in mature kelp and seaweed vegetation (Christie et al., 2009). A longer time period is needed to establish a rich and diverse kelp fauna community at experimental plots so far from natural faunal sources.

3.5 Ecosystem services and CO_2 binding

In addition to kelp growth, large annual production, and habitat for diverse invertebrate and fish ecosystems, kelp also provide other ecosystem services such as cleaning water and taking up CO_2. Binding and sequestration of blue forests have been given attention and particular the large export of kelp to deeper waters has been focused. Using the numbers of Gundersen et al. (2011), if each cage promoted recovery of ca 90 kg of kelps (i.e. 10 kg per m^2), this will bind about 32 kg of CO_2. Of this, between 1 and 2 kg CO_2 will be buried (sequestrated) in sediments and deeper waters each year, if the kelp population persisted.

In contrast to this small scale experiment, the Norwegian urchin barrens are very extensive the potential for large scale recovery over time if sea urchin harvest could be sufficiently removed to promote a complete kelp recovery, and an estimate of 3-8% of the particulate organic material (POM) from kelp will be buried in the sediments, this implies a sequestration of 0.9-2.3 million tonnes/year on a national basis. If all Norwegian kelp forest grew back, there would be a one-time binding of 36 million tons of additional CO_2. (Gundersen et al., 2011).

3.6 Outreach and communication of results

This project has had an extensive focus on outreach and communication and has been mentioned in several local, national and international media.

Some example of outreach follows below:
- The deployment was filmed by Norwegian National TV (NRK), which was sent 28th of November 2018 on national TV.
- A Japanese film team from TV Tokyo visited Tromsø in February 2019 during their work on a 90 minutes documentary on the future of global fisheries. Harm Kampen, Brian Tsuyoshi, Philip James and Dr. Pernilla Carlsson were interviewed and filmed during a demonstration of urchin harvesting.
- The sea and fish industry magazine TekFisk interviewed Dr. Pernilla Carlsson in April 2019 about the impact of urchins on kelp forest.
- Forskning.no; Dr Pernilla Carlsson and the NIVA kelp and urchin research group published a chronicle on the main Norwegian research outreach platform www.forskning.no in August 2019. "5 reasons to eat urchins". This chronicle was re-cited in September 2019 in KK (kvinner og klær; Norwegian women lifestyle magazine) and Norsk barneblad; Norwegian magazine for children.

Links to published outreach: Tekfisk: https://fiskeribladet.no/tekfisk/nyheter/?artikkel=65994 forskning.no: https://forskersonen.no/hav-og-fiske-havet-mat/5-gode-grunner-til-a-spise-krakeboller/1550363. Re-cited in KK: https://www.kk.no/helse/5-gode-grunner-til-a-spise-krakeboller/71562534 and Norsk barneblad: https://www.barneblad.no

In addition, Fuglefjellet AS and David González have documented the work under water from October until June and have a collection of photo and video material that can be used for further outreach and communication. Any inquires regarding this material should be sent to Toivo Nilsen at Fuglefjellet: toivo@fuglefjellet.no.

3.7 Future work

This project will move into a collaboration between one diving club in Tromsø (SUT; Studentenes undervannsklubb i Tromsø) and Urchinomics. The volunteer diving club SUT will collect urchins and send them to Rogaland Havbrukpark in southwest Norway for feeding the urchins before they are launched on the commercial market.

4 Conclusions and recommendations

Overall, the density of sea urchins in the experiment area (inside the three cages) were kept on a minimum during the project, and kelp species such as *Alaria esculenta* and *Saccharina latissima* settled and grew during spring. However, once the kelp was established in the cages, the area became very attractive for sea urchins that began to climb onto and into the cages for feeding. Our recommendation for future experiments and attempts to limit sea urchin grazing is to collect urchins more often (probably closer to once a week) during summer. Another alternative would be to make the cages in a different material and to include a top “roof” that would prevent urchins from climbing into the cages. Whether this would affect the possibilities for kelp spores to settle inside the kelp needs to be tested. A third alternative is to make larger cages or clear larger areas that could make detection of intruding urchins easier.

The results from this project clearly shows that kelp could re-colonise an area when sea urchins were removed. Collecting of sea urchins for commercial interests could walk hand in hand with interests for gradually restoring valuable kelp forests.

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